Update on One Hundred Watt HVM LPP-EUV Light Source

2015 International Workshop on EUV Lithography

Dr. Hakaru Mizoguchi
CTO & Executive Vice President
Gigaphoton Inc.

DOC#: ED15L-214

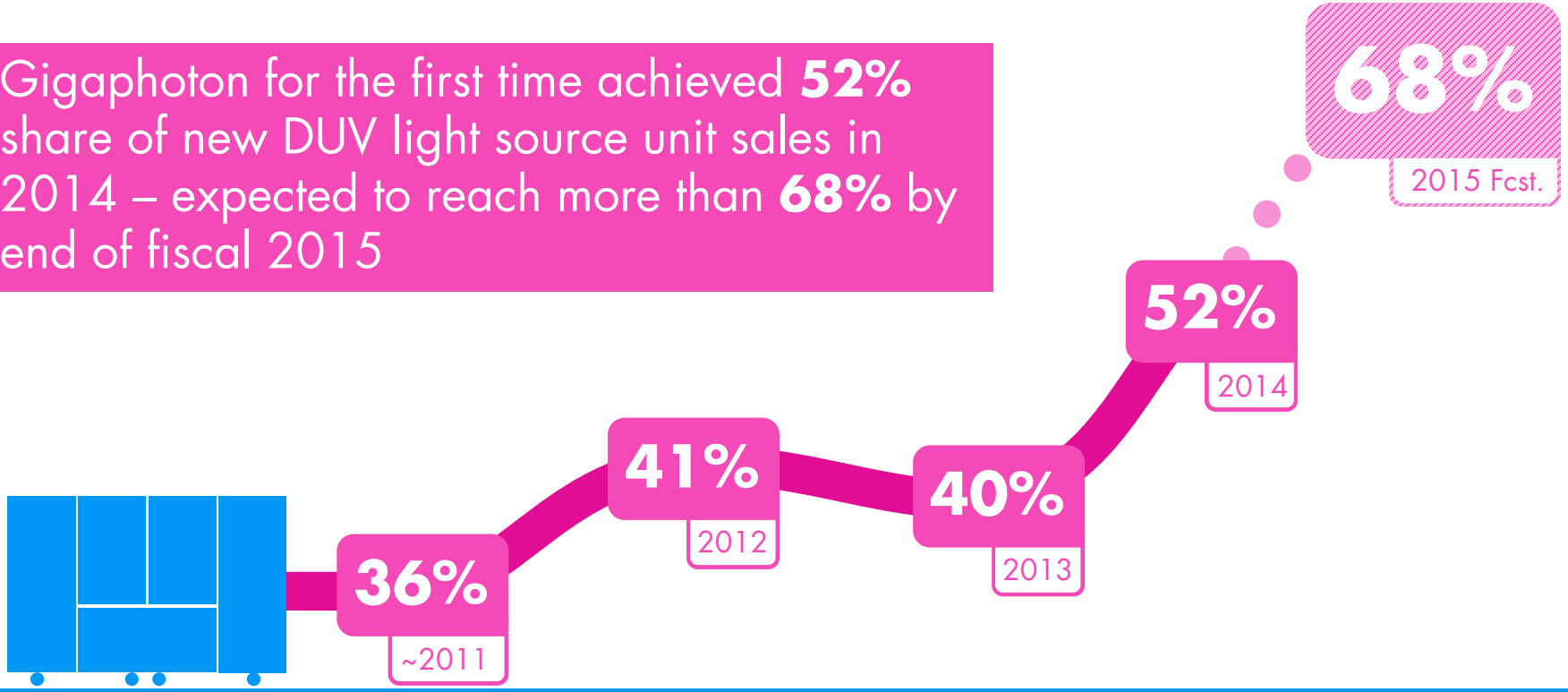
GIGAPHOTON

OUTLINE

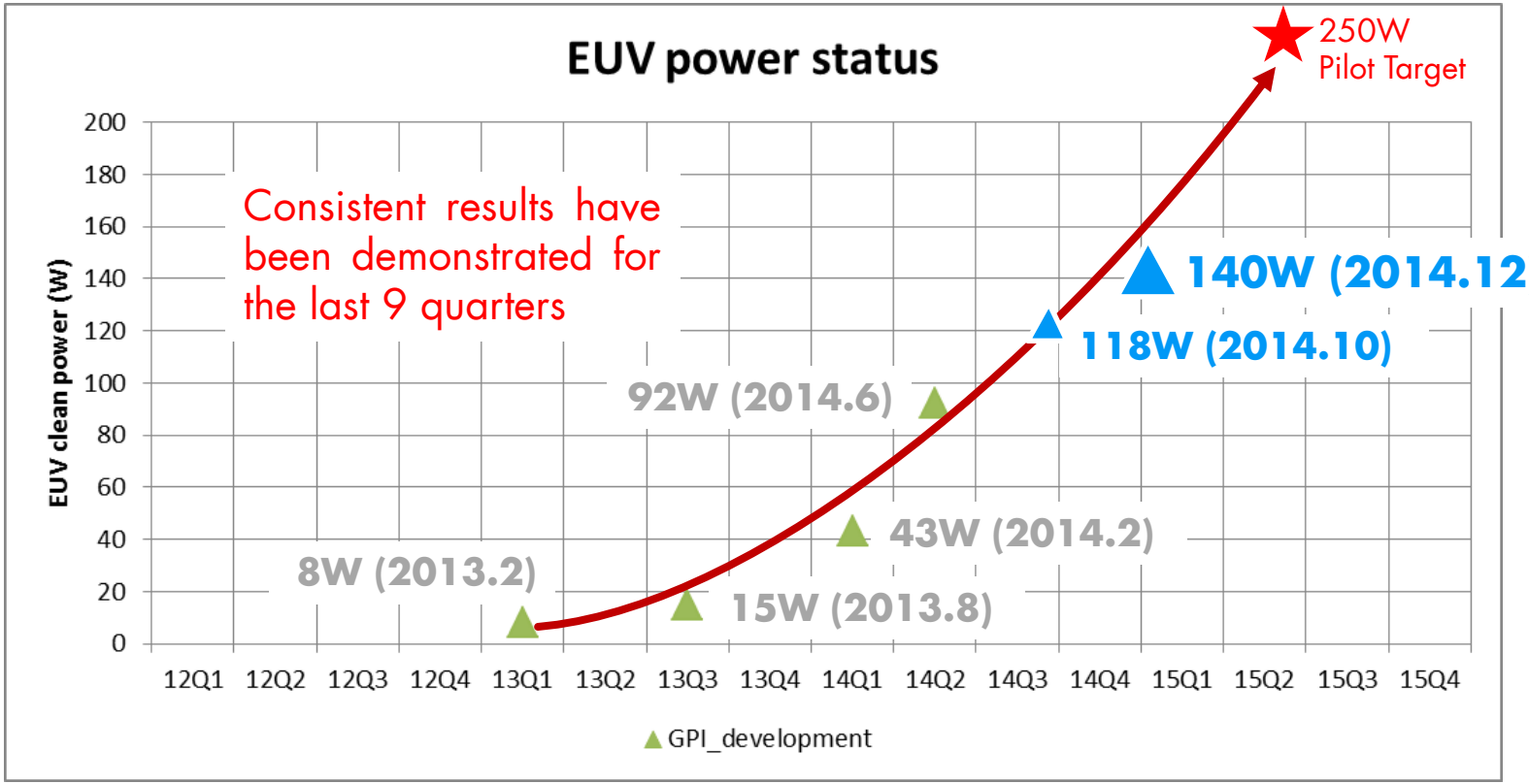
- Introduction
- Prototype LPP Source System Development Update
  - » Gigaphoton's LPP Light Source Concept
  - » Gigaphoton's EUV Source Configuration
  - » Proto Device #1
    Debris Mitigation Technology Update
  - » Proto Device #2
    High Power Operation Data Update
- New Pilot System Development Update
- Summary

DUV Installations are Rapidly Growing

Gigaphoton for the first time achieved **52%** share of new DUV light source unit sales in 2014 – expected to reach more than **68%** by end of fiscal 2015



EUV Power Achievements and Target

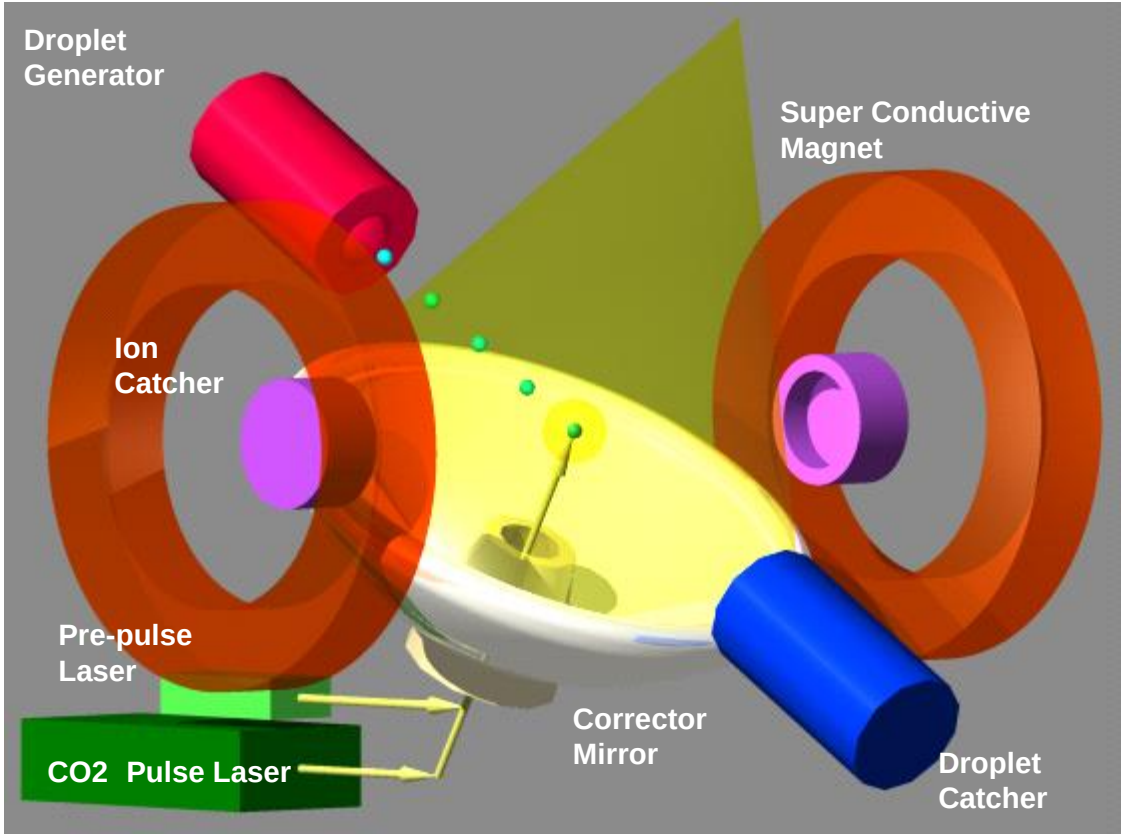


OUTLINE

- Introduction
- Prototype LPP Source System Development Update
  - » Gigaphoton's LPP Light Source Concept
  - » Gigaphoton's EUV Source Configuration
  - » Proto Device #1
    Debris Mitigation Technology Update
  - » Proto Device #2
    High Power Operation Data Update
- New Pilot System Development Update
- Summary

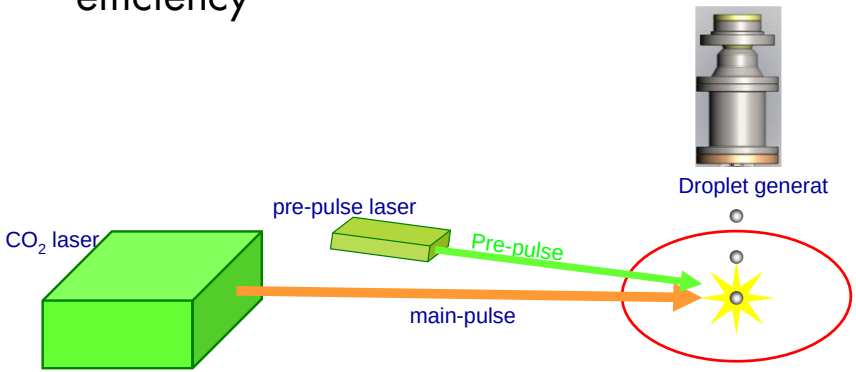
Gigaphoton's LPP Light Source Concept

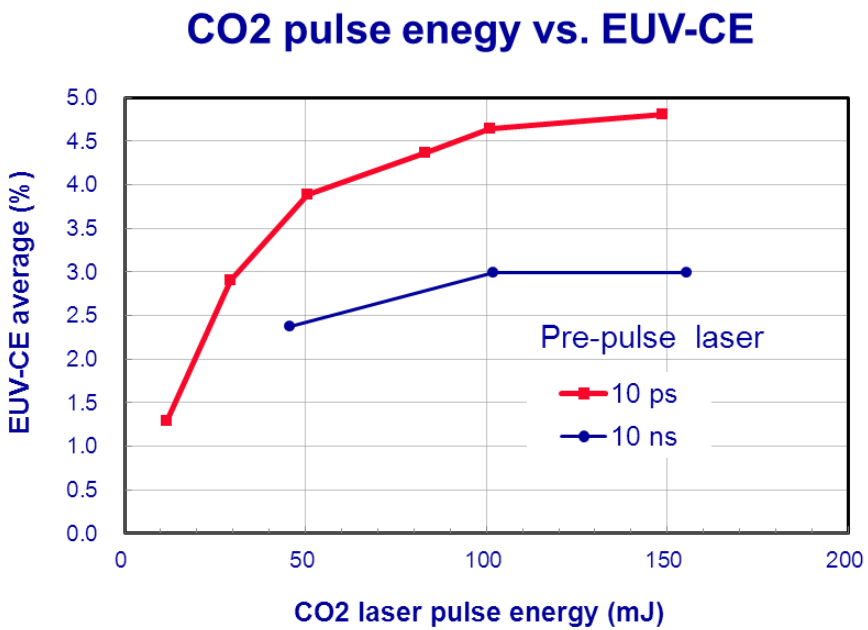
- High ionization rate and CE EUV tin (Sn) plasma generated by CO_2 and pre-pulse solid laser dual wavelength shooting
- Hybrid CO_2 laser system with short pulse high repetition rate oscillator and commercial cw-amplifiers
- Accurate shooting control with droplet and laser beam control
- Tin (Sn) debris mitigation with a super conductive magnetic field
- High efficient out of band light reduction with grating structured C1 mirror



Pre-Pulse Technology (1)

- Based on basic physical consideration and experiments, Gigaphoton has chosen to adopt the pre-pulse technology since 2009
- In 2012 Gigaphoton discovered that shortening the pre-pulses duration dramatically enhance the conversion efficiency

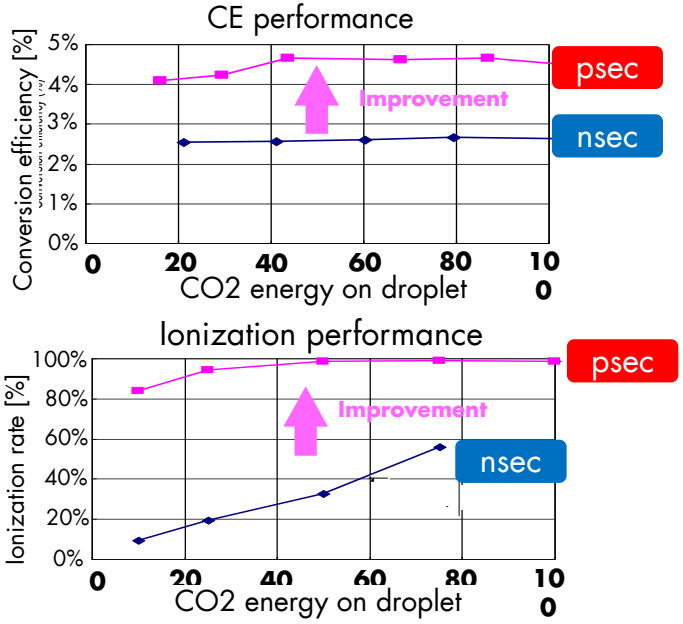




Pre-Pulse Technology (2)

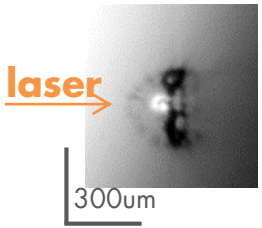
Experiment shows picosecond pre-pulse dramatically enhances ionization rate and CE

Data in 10Hz Experimental Device

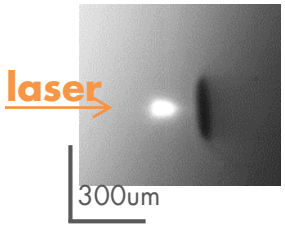


Sn Droplet Smash

psec — Dome like target



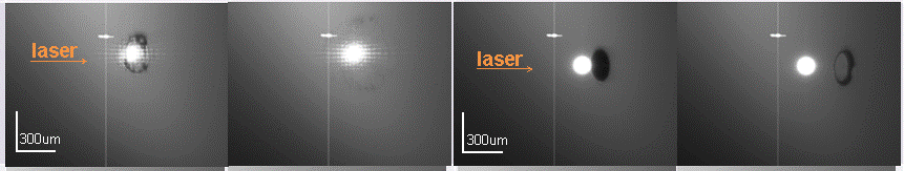
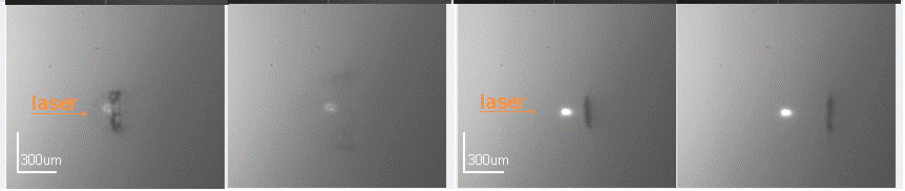
nsec — Flat disk like target

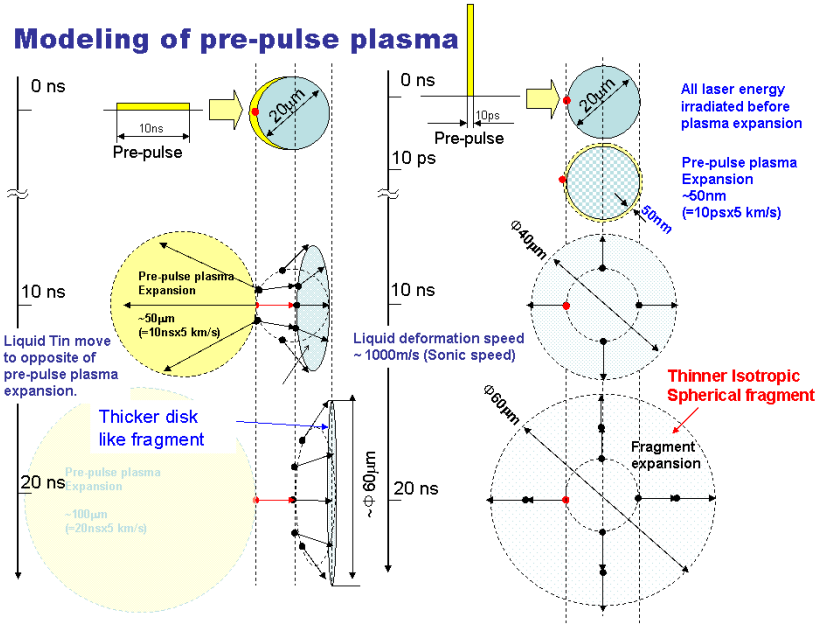


Pre-Pulse Technology (3)

Fragment distribution measurement

- The mist shape of a picosecond pre-pulse is different from the nanosecond
- Nano-cluster distribution could be a key factor for high CE

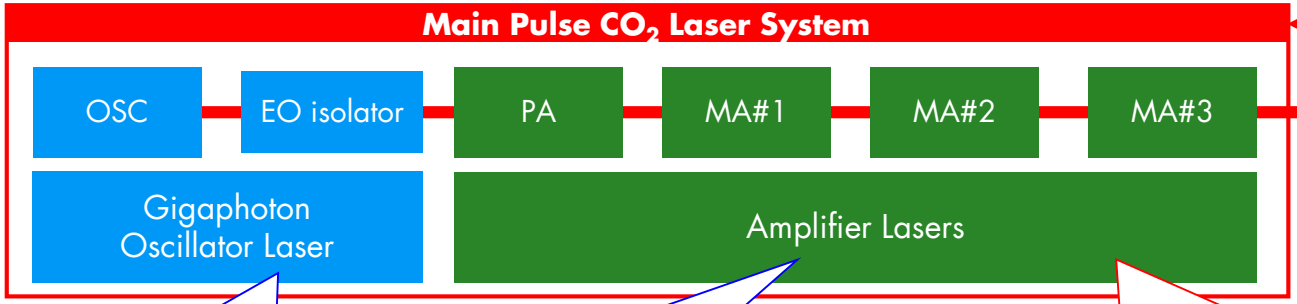
	10 ps		10 ns	
Pulse energy	2.0 mJ		2.7 mJ	
delay	1 μs	2 μs	1 μs	2 μs
60 deg view				
90 deg view				

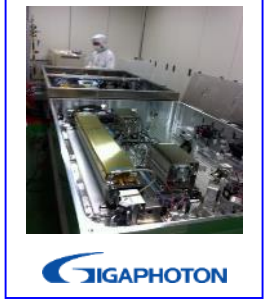


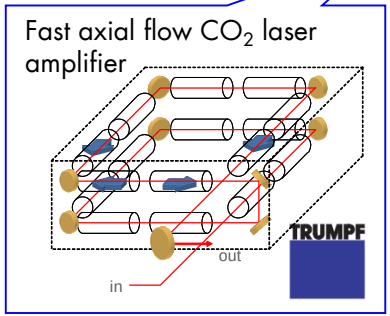
High Power CO_2 Laser Technology (1)

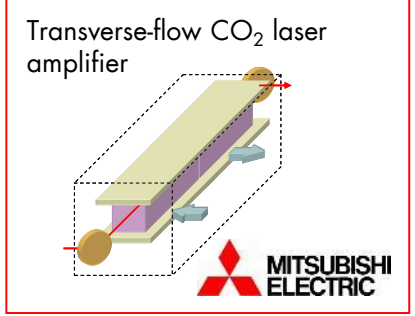
Driver Laser System

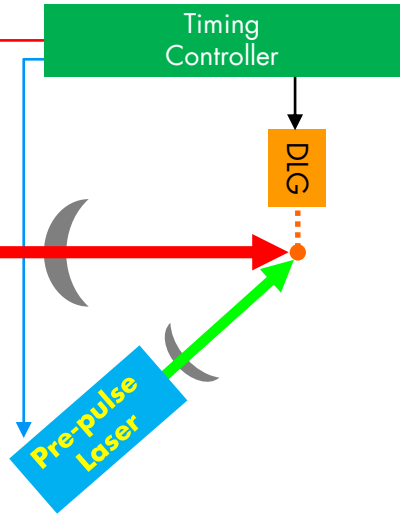
Gigaphoton, in cooperation with CW-CO_2 laser companies, has been jointly developing a unique high power pulsed CO_2 laser system since 2004











Pre-pulse Laser Performance	
Wavelength	1064.3nm
Max Pulse Energy	1mJ
Pulse Duration	12ps
Rep Rate	single~120kHz
Average Power	100W

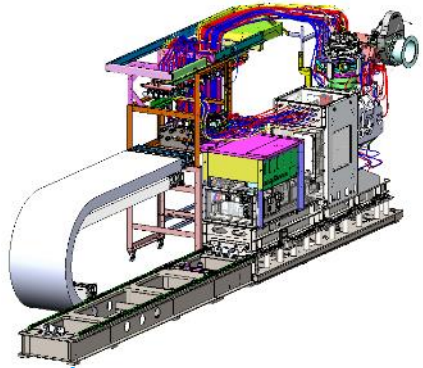
High Power CO_2 Laser Technology (2)

	Target at Plasma	System	Oscillator	Pre-Amplifier	Main Amplifier	
Proto #1	5kW	Endurance Testing Platform	GPI	R	T	T
	8kW	Power Up Testing	GPI	R	T	T	T
Proto #2	14kW	Power Up Testing	GPI	M	T	T	T
Under Construction Pilot #1	>20kW	Customer Beta Unit	GPI	M	M	M	M

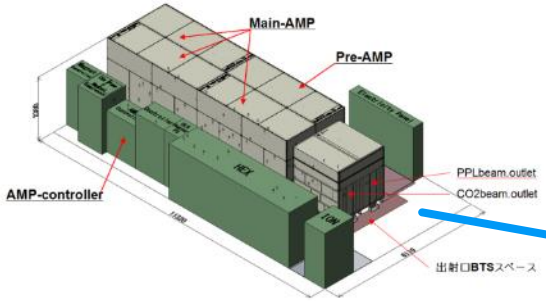
validated performances at system

Gigaphoton EUV Sources

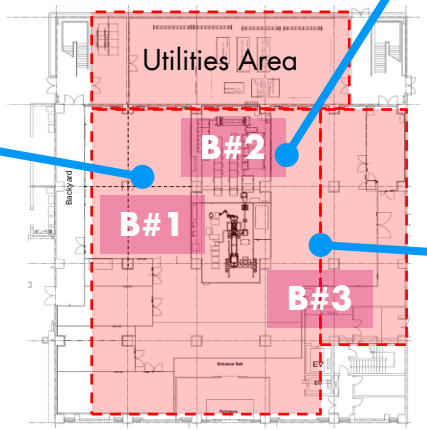
2 – proto system are in operation
1 – pilot system is under construction



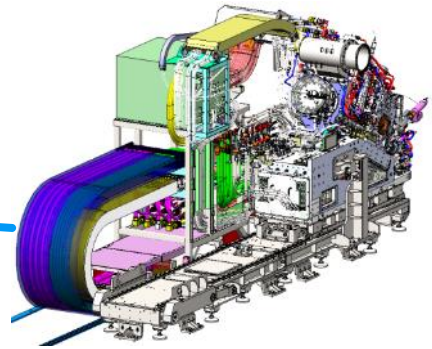
Proto #1
From Oct 2012



Pilot #1 NEW
(under construction)



Proto #2
From Nov 2013



Proto Systems in Operation

Target System Specification

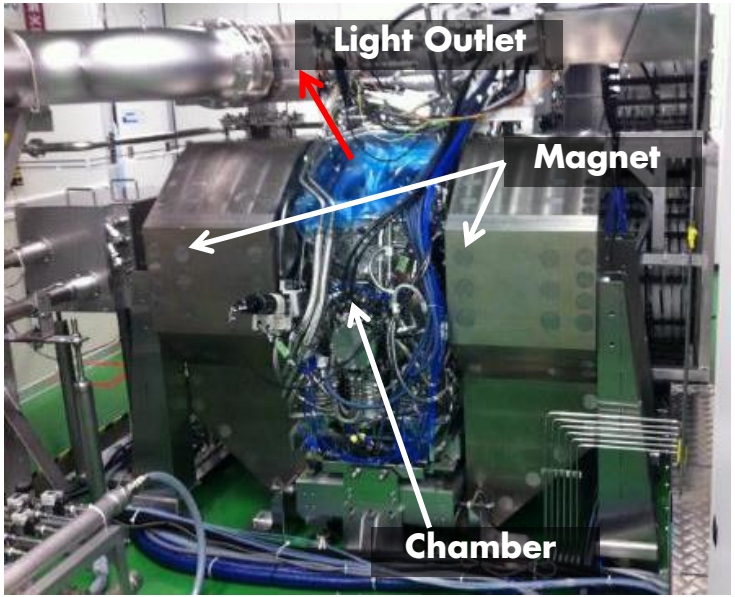
Operational Specification		Proto #1	Proto #2	Pilot #1 (under construction)
Target Performance	EUV Power	25 W	> 100 W	250 W
	CE	3%	4%	4%
	Pulse rate	100 kHz	100 kHz	100 kHz
	Output angle	Horizontal	62° upper (matched to NXE)	62° upper (matched to NXE)
	Availability	1 week operation	1 week operation	> 75%
Technology	Droplet generator	20 – 25 µm	20 µm	< 20 µm
	CO2 laser	> 8 kW	> 12 kW	25 kW
	Pre-pulse laser	picosecond	picosecond	picosecond
	Debris mitigation	validation of magnetic mitigation in system	10 days	> 30 days

Gigaphoton's High Power EUV Light Source

Prototype high power EUV light source is in operation

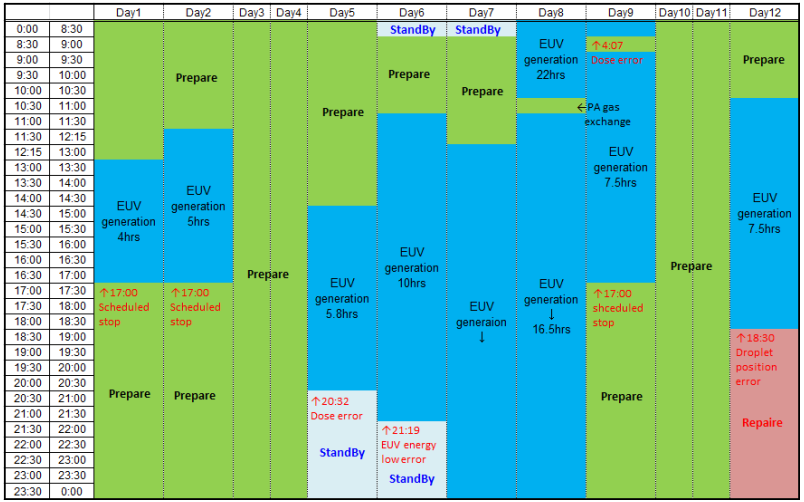
Proto 1 Exposure & Mitigation test

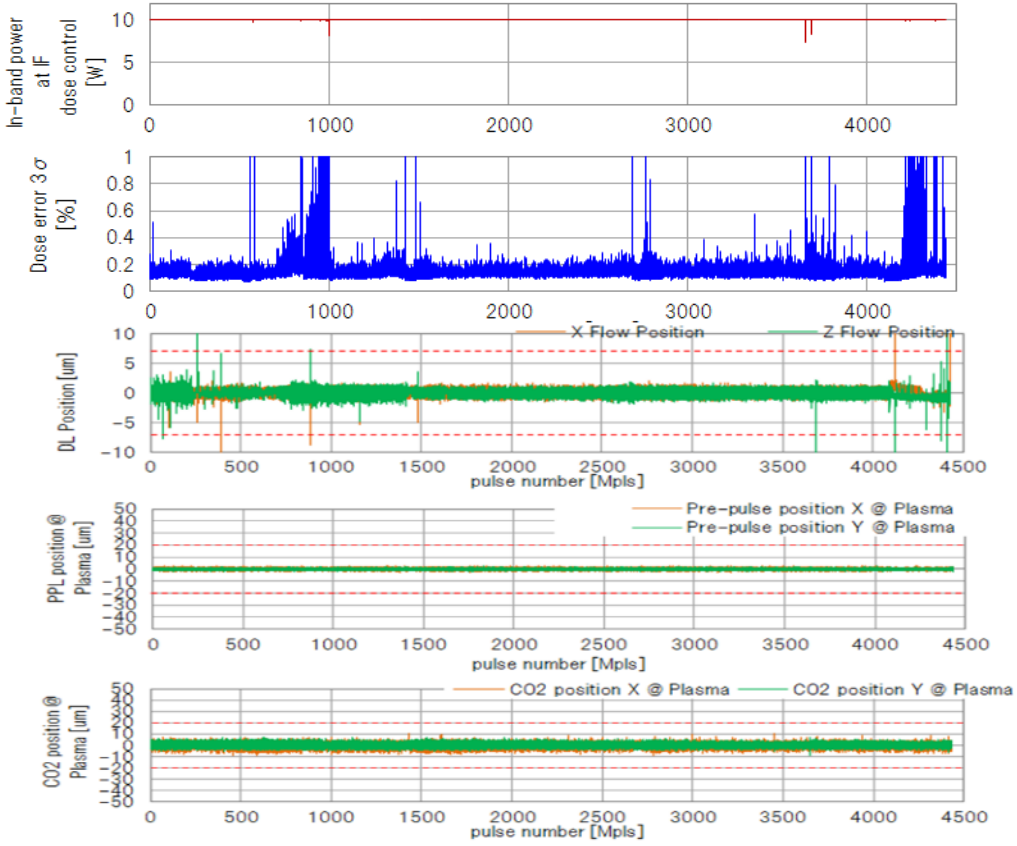
Proto 2 High power Experiment



Proto#1: 77 hrs. EUV Emission

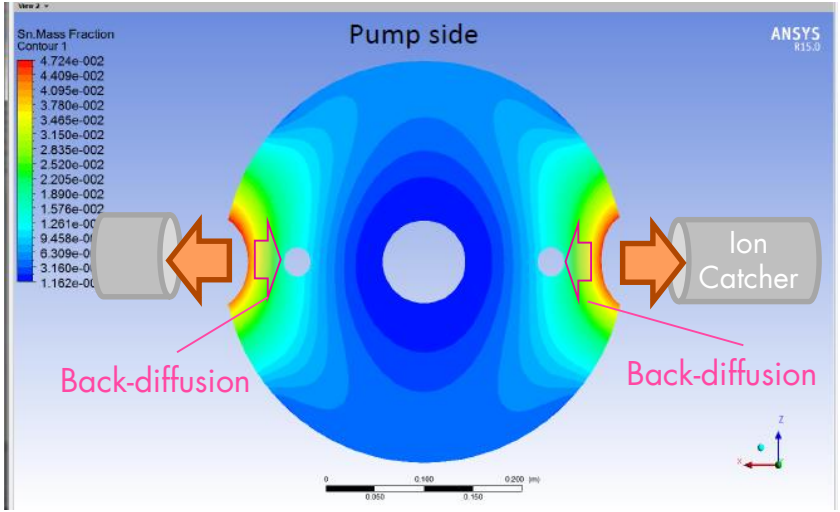
- Average power 10W with dose control, **77 hrs.** EUV emission was achieved by Proto#1 (total operation time is **261 hrs.**)
- Total pulse number is 4.4 Bpls.
- Dose stability 3 sigma typically < 0.3%



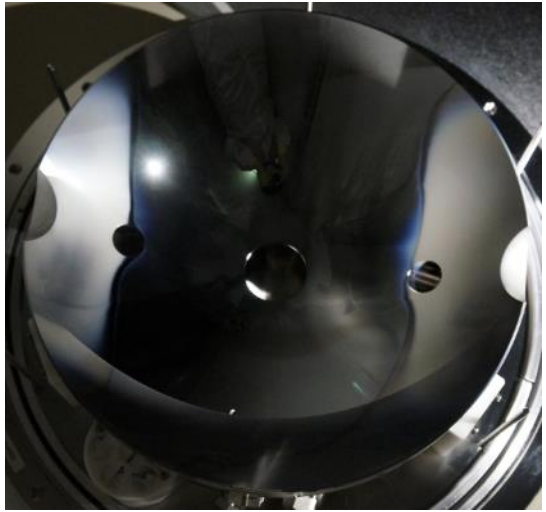


Tin Back-diffusion Issue from the Ion Catcher

- Issue: tin depositions on mirror caused by back-diffusion from the ion catcher
- Reduction of the back-diffusion from the ion catcher is key



Tim Deposition Simulation

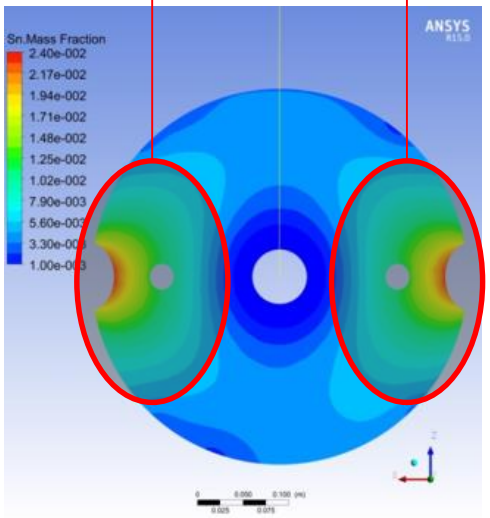


Actual Tin Deposited on Collector

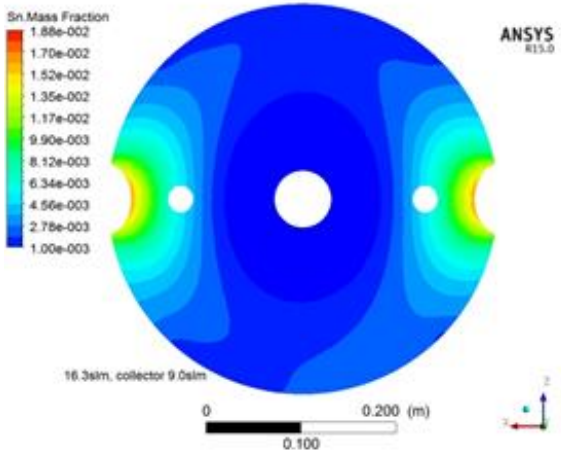
Tin Back-diffusion Issue from the Ion Catcher

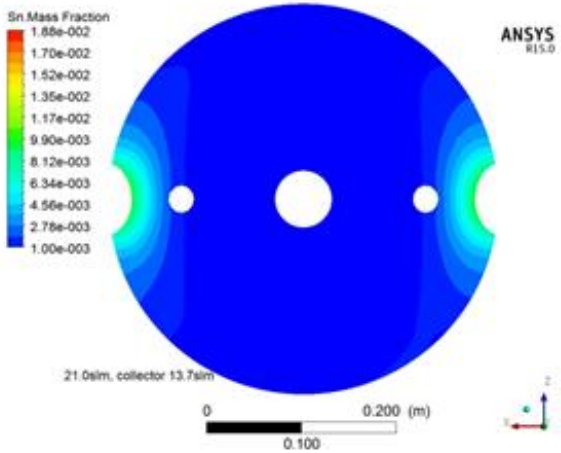
Progress of resolving back-diffusion issue

unwanted tin (Sn) debris



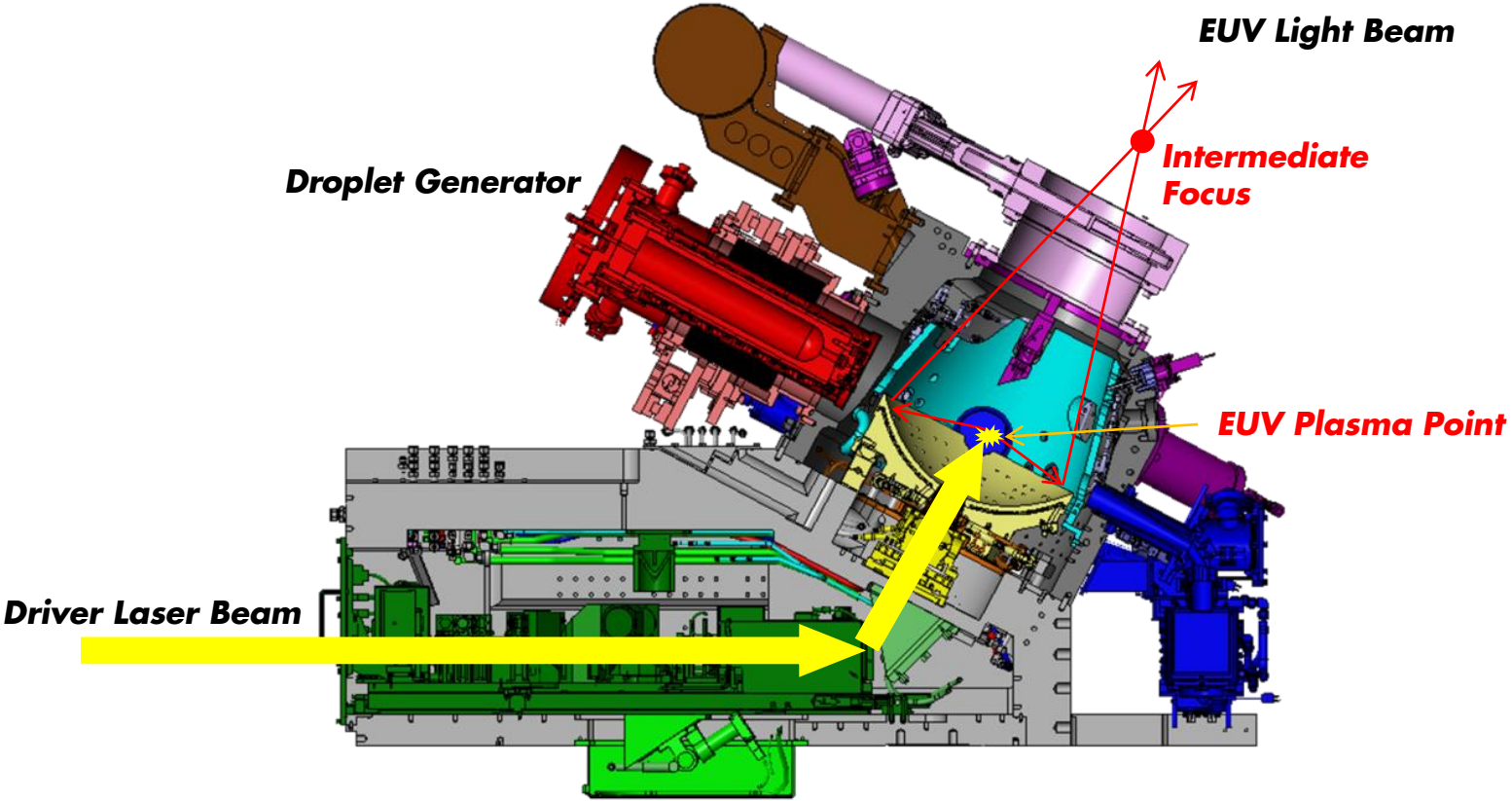
Improvement of back-diffusion from the ion catcher is very clear





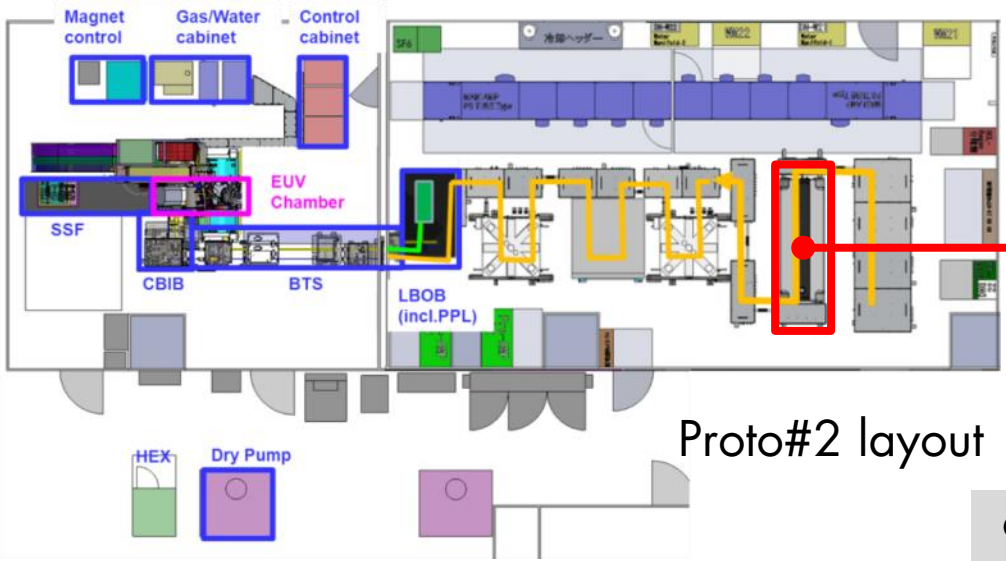
Oct. 2014 | **Nov. 2014** | **Present (Testing)**

Proto #2 System for High Power Testing



Proto #2 System Layout

Mitsubishi pre-amplifier was installed in Proto #2 and performance was confirmed



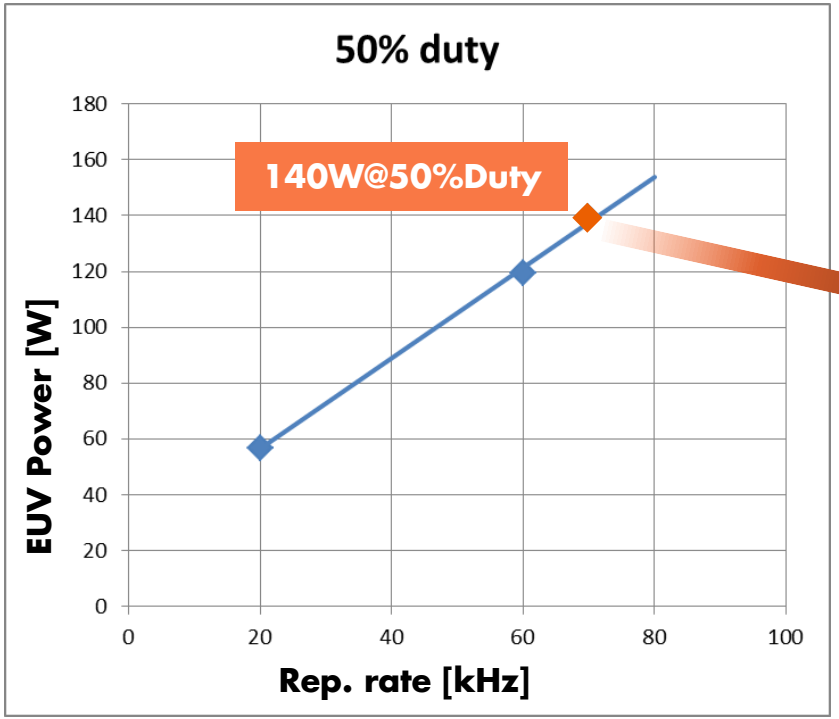
Proto#2 layout

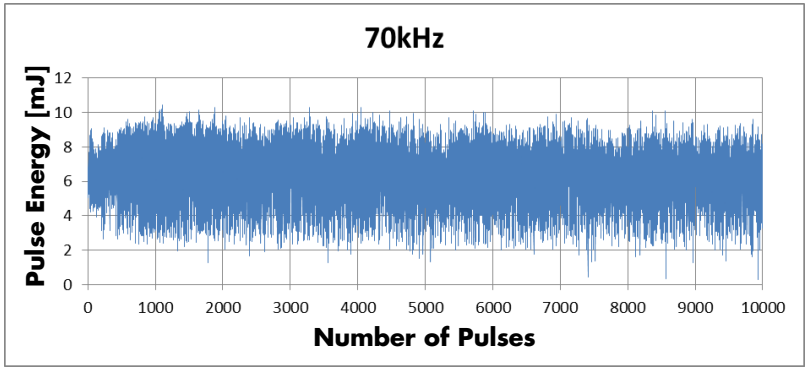
GPI — Mitsubishi — Trumpf — Trumpf — Trumpf

MA#1 MA#2 MA#3

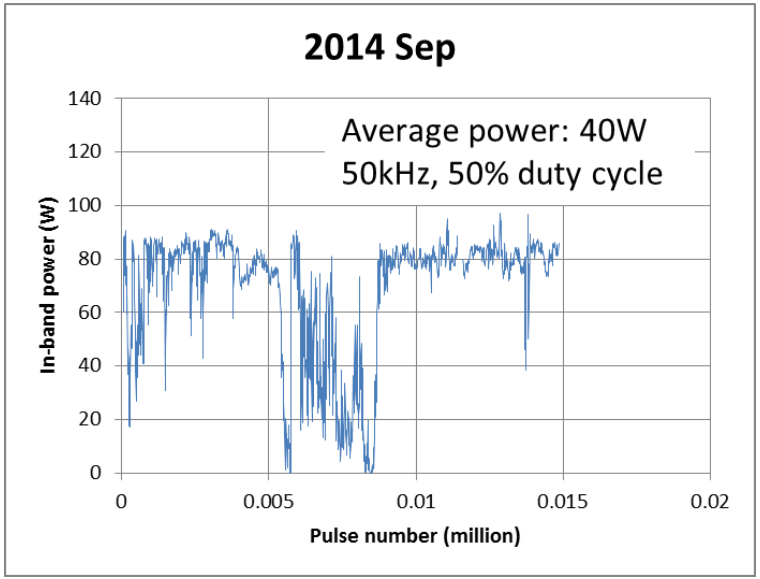
Proto #2 EUV Power Data

Champion Data: 140W EUV in burst power with 70kHz, 50% duty cycle

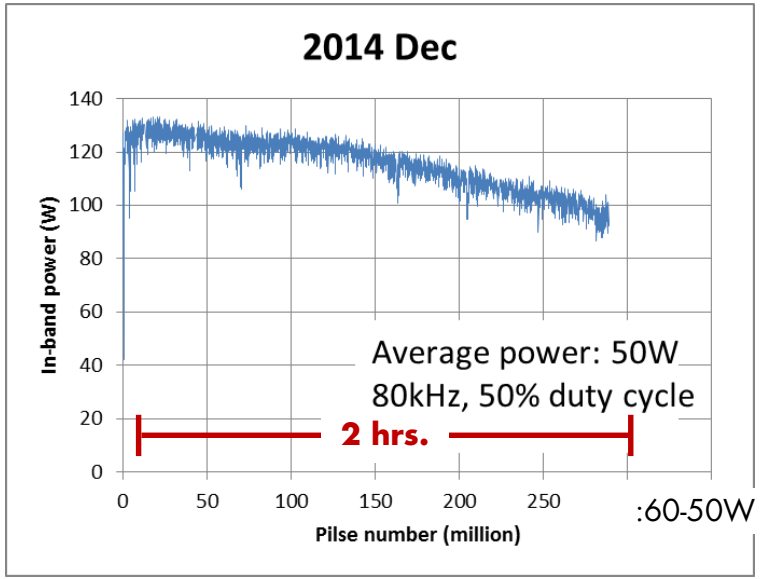




Proto #2 EUV Power Data



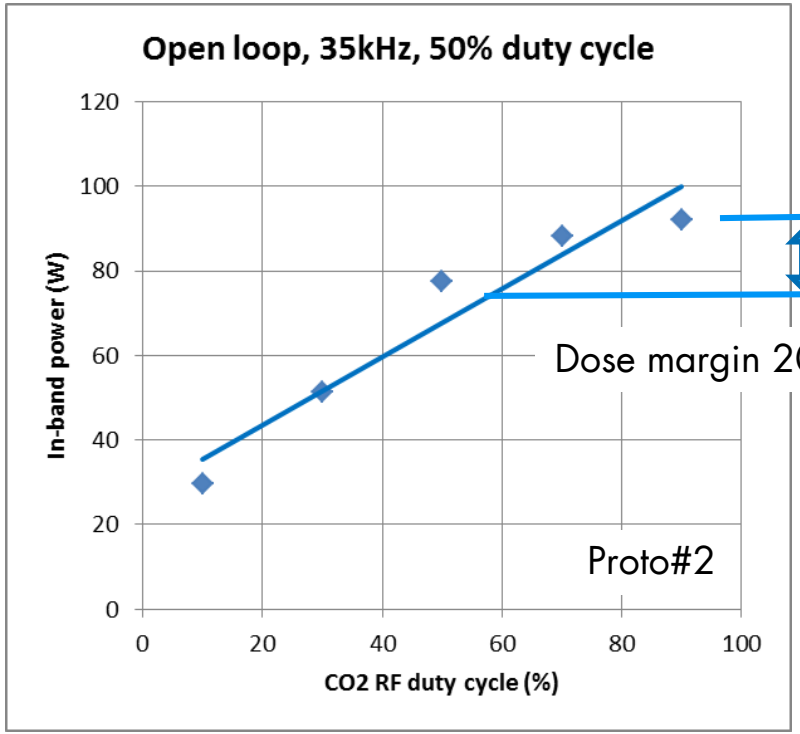
(data shown at EUV Symposium 2014)

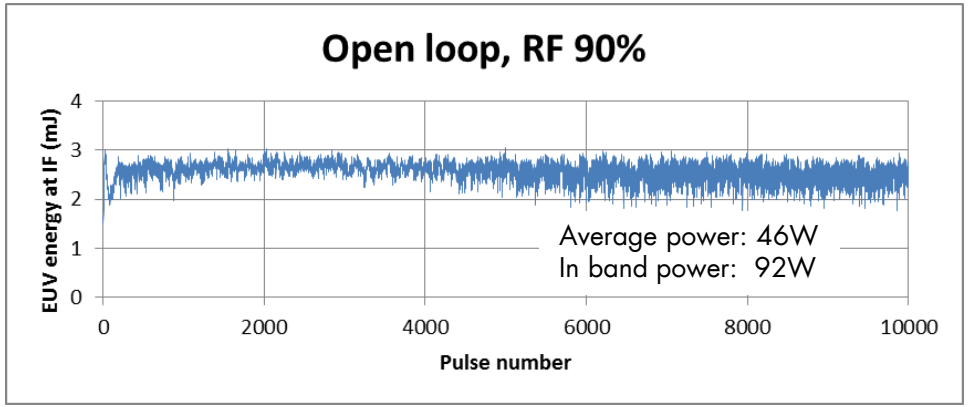


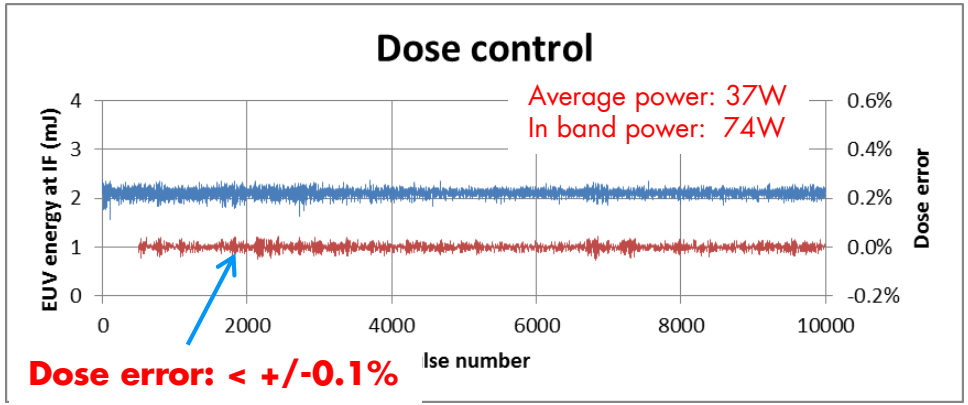
120-100W in-burst, 80kHz, 50% duty cycle (Clean power in burst) during 120min
Output power **60-50W (120-100W @ 50% duty) average during 120 min.**.

Proto#2: Dose control performance

20% dose margin

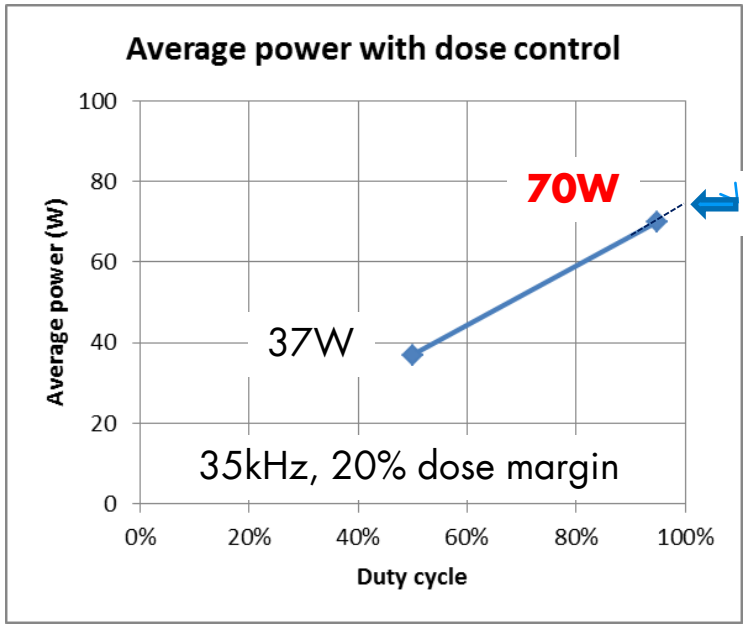


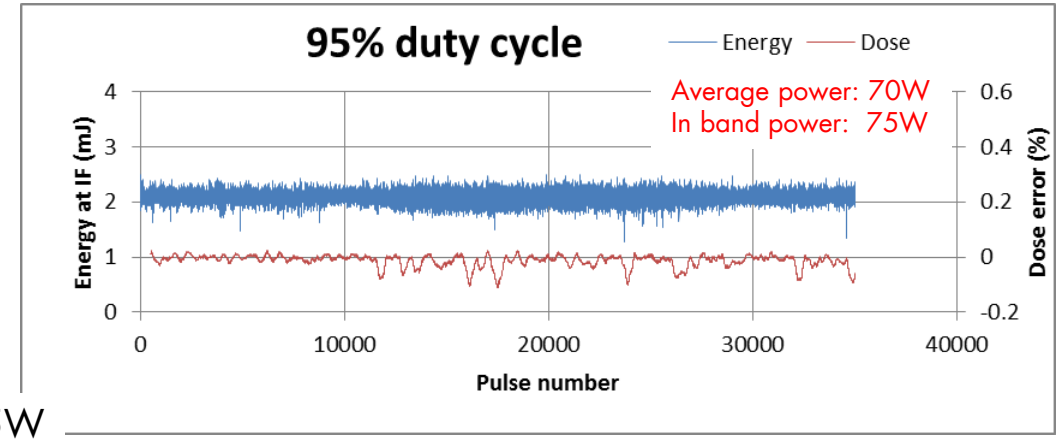


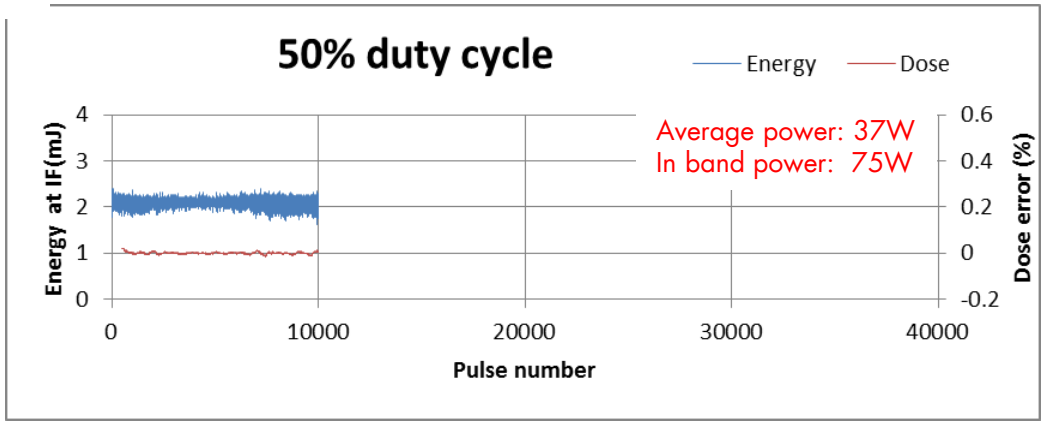


Proto#2: High Duty Cycle with Dose Control

Dose control capability up to 95% duty cycle with 20% dose margin was confirmed in proto#2 system at 75W in burst, 70W in average level operation

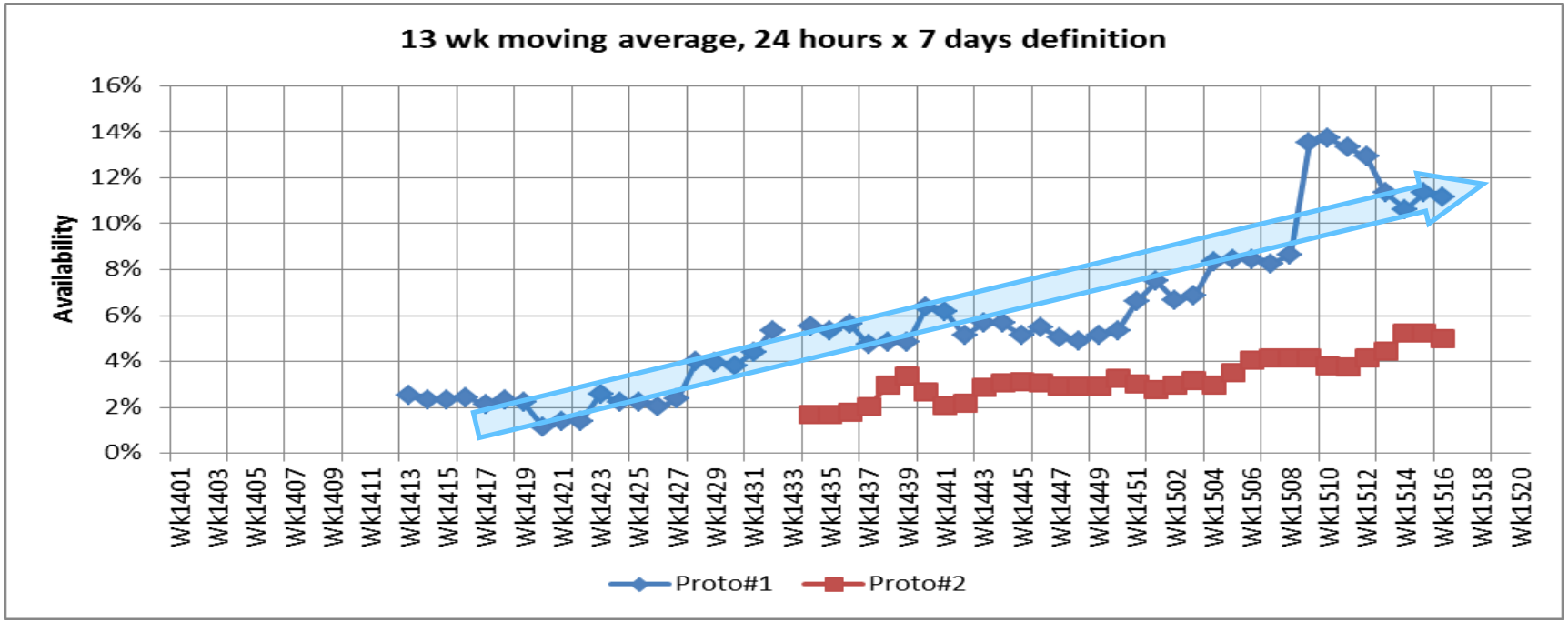






Availability Status

Availability is continuously increasing in 13wk level moving average.



OUTLINE

- Introduction
- Prototype LPP Source System Development Update
  - » Gigaphoton's LPP Light Source Concept
  - » Gigaphoton's EUV Source Configuration
  - » Proto Device #1
    - Debris Mitigation Technology Update
  - » Proto Device #2
    - High Power Operation Data Update
- New Pilot System Development Update
- Summary

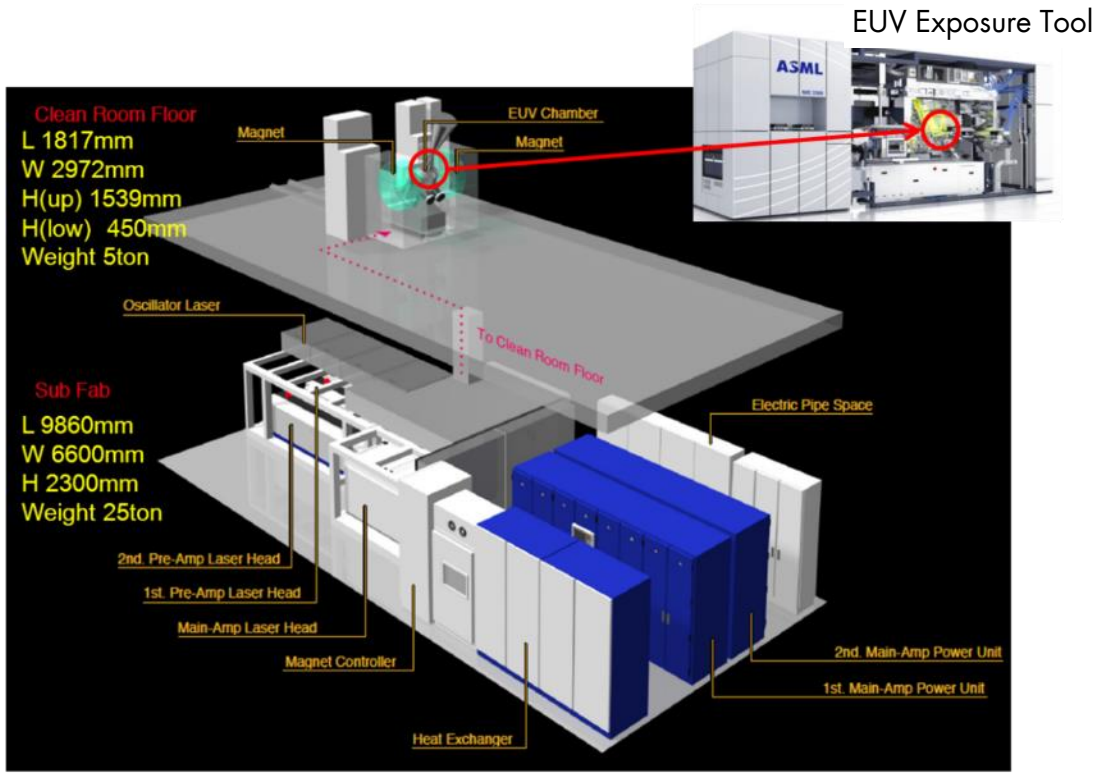
Pilot #1 EUV Light Source for HVM

Layout of 250W EUV Light Source

First HVM EUV Source

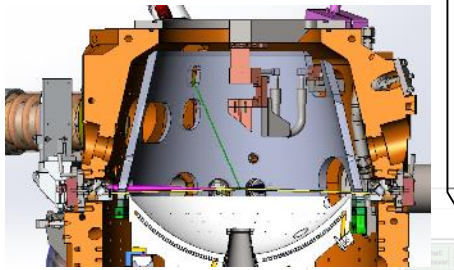
- 250W EUV source

Operational specification (Target)			HVM Source
Performance	EUV Power		> 250W
	CE		> 4.0 %
	Pulse rate		100kHz
	Availability		> 75%
Technology	Droplet generator	Droplet size	< 20mm
	CO2 laser	Power	> 20kW
	Pre-pulse laser	Pulse duration	psec
	Debris mitigation	Magnet, Etching	> 15 days (>1500Mpls)

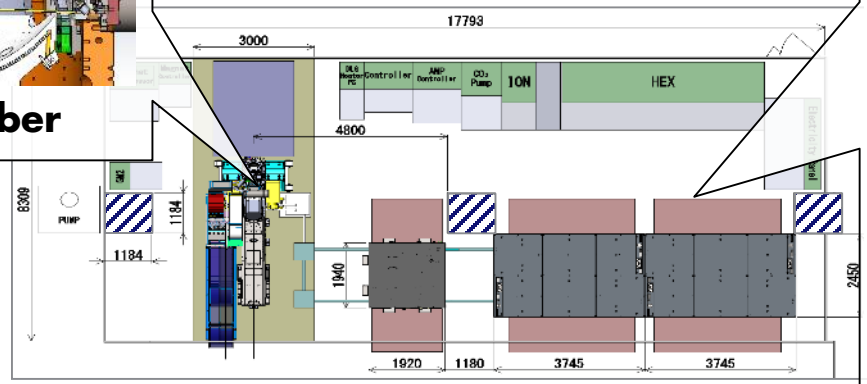


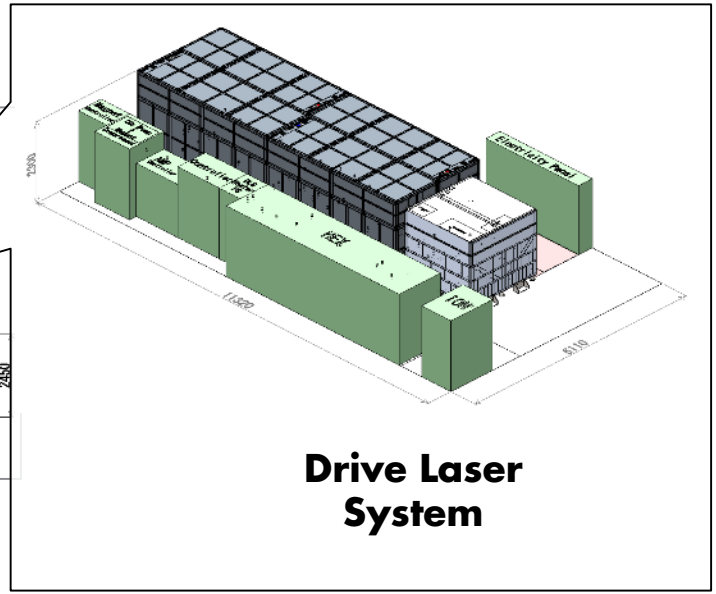
EUV Pilot #1 Light Source or HVM

CO_2 laser construction in progress – target spec. is >27KW



EUV Chamber





Drive Laser System

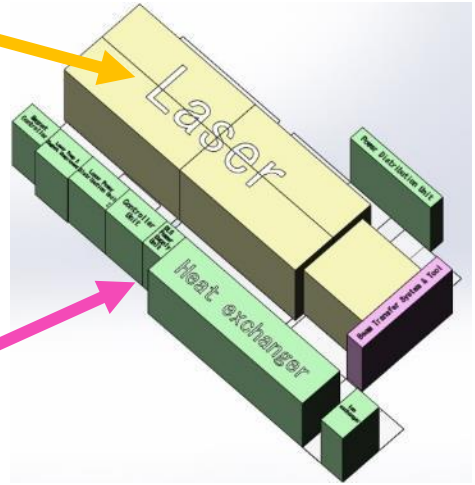
Utility Specification (EXPECTED)

- GPI specification of Pilot#1.
- It is remarkable low consumption compare with other source.

Pilot#1 Specification	Value	Units
EUV Power	250	W
Electrical power input (at full load)	880	kVA
Thermal load to water	780	kW
Cooling water flow rate (at 17 °C)	1608	L/min
Hydrogen gas consumption	30	NL/min

EUV Pilot #1 construction status update

- Driver laser: All amplifiers are delivered, assemble will complete end of July 2015
- EUV Chamber: Under designing. Device will complete end of September 2015



OUTLINE

- Introduction
- Prototype LPP Source System Development Update
  - » Gigaphoton's LPP Light Source Concept
  - » Gigaphoton's EUV Source Configuration
  - » Proto Device #1
    Debris Mitigation Technology Update
  - » Proto Device #2
    High Power Operation Data Update
- New Pilot System Development Update
- Summary

Power-Up Milestones

We are achieving **solid** and **steady** progress towards realizing our HVM EUV source

				Proto #2 (current work)	**Pilot #1** (under construction)
EUV clean power	25W	43W	92W	**140W**	**250W**
Target	2013, Q4	2014, Q1	2014,Q2	**2014,Q4**	**2015,Q3**
CO_2 power at plasma	5kW	8kW	14kW	**>14kW**	**> 20kW**
CE	2.5%	3%	4.2%	**>4.2%**	**> 4.5%**
Plasma to IF clean	21.7%	21.7%	21.7%	**26.7%**	**26.7%**
CO_2 laser	2 main amp. system: Proto#1	3 main amp. system: Proto#2	Mitsubishi pre-amp.: Proto#2	**Mitsubishi pre-amp: Proto#2**	**Mitsubishi main amp. system**
Collector mirror	Normal Type	Normal Type	Normal Type	**Grating Type**	**Grating Type**

Summary

- Progress of Proto #1 unit
  - » Further improvement of “Magnetic debris mitigation”
  - » Simulation expect further improvement of back-diffusion
  - » New 77 hrs., 10W operation data without maintenance was reported
- Progress of Proto #2 unit
  - » Driver CO2 laser system achieved 20 kW with pre-amplifier by Mitsubishi Electric
  - » Maximum power champion data:140 W (CE 3.7%) in burst at 70 kHz, 50% duty
  - » 120-100 W power in burst, 50% duty, (60-50 W average) for120 min.
  - » Reported new data: Dose control capability is proved experimentally (control margin 20%), until 95% duty cycle with 75W in burst level (70W in average power)
  - » Next step is higher average power (>100W) operations during more than 24 hrs.
- Pilot #1 is under construction
  - » Design of system is almost fixed - most parts are already ordered
  - » Construction will finish in Q3, 2015. First data will be expected in Q4, 2015

Acknowledgements

Thanks for co-operation:

Mitsubishi electric CO_2 laser amp. develop. team: *Dr. Yoichi Tanino**, Dr. Junichi Nishimae, Dr. Shuichi Fujikawa and others.

** The authors would like to express their deepest condolences to the family of Dr. Yoichi Tanino who suddenly passed away on February 1st, 2014. We are all indebted to his incredible achievements in CO_2 amplifier development. He will be missed very much.*

Dr. Akira Endo :**HiLase Project** (Prague) and Prof. Masakazu Washio and others in **Waseda University**
Dr. Kentaro Tomita, Prof. Kiichiro Uchino and others in **Kyushu University**
Dr. Jun Sunahara, Dr. Katsunori Nishihara, Prof. Hiroaki Nishimura, and others in **Osaka University**

Thanks for you funding:

EUV source development funding is partially support by **NEDO（ New Energy and Industrial Technology Development Organization） in JAPAN**

Thanks to my colleagues:

EUV development team of Gigaphoton; Hiroaki Nakarai, Tamotsu Abe, Takeshi Ohta, Krzysztof M Nowak, Yasufumi Kawasuji, Hiroshi Tanaka, Yukio Watanabe, Tsukasa Hori, Takeshi Kodama, Yutaka Shiraishi, Tatsuya Yanagida,Tsuyoshi Yamada, Taku Yamazaki, Takashi Saitou and other engineers.

THANK YOU

GIGAPHOTON